Chapter - 3

Influence of MMT Dispersion on Mechanical, Thermal and Fire Retardation Properties of Vinylester/Glass Composites

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3.1 Introduction

Effect of fillers on the composite properties mainly depends on their concentration, particle size and shape of the fillers and their interaction with the matrix as well as compatibility [1]. Montmorillonite (MMT) is preferred nanofiller for polymer nanocomposites. It is an expandable dioctahedral smectite belonging to the family of 2:1 phyllosilicates. Its particles consist of stacks of 1 nm thick aluminosilicate layers (or platelets) with a regular interlayer gap. It has a large surface area of 750 m²/g and high aspect ratio [2-4]. It has a low surface charge density of 0.25-0.5 equiv. mol⁻¹, due to which the interparticle force of attraction that aids in either intercalation/exfoliation within the polymer system have been successfully used to improve mechanical, thermal, barrier and fire retardation properties at very low loadings of < 5 wt% of nanofillers [5-10]. Thus, MMT based polymer nanocomposites are considered for applications in a wide variety of areas, such as aerospace, marine, electronics and automotive industries [11-13].

Anirban Ganguly et al [14] studied MMT dispersed rubber nanocomposites for tensile behavior and reported 33% and 57% improvements in tensile strength and tensile modulus respectively due to the addition of 3 wt % MMT to rubber. The authors also reported increase in storage modulus at room temperature and shift of tan δ peak towards positive temperature. The authors attributed the improvements to better polymer–filler interaction resulting in good exfoliation as per AFM characterization.

A Leszczynska et al [15] investigated the thermal properties of MMT/polybenzoxazine and reported that 5 wt % MMT was effective to improve the weight residues for nanocomposites. The char yield at 800°C increased by 20 % due to 5 wt % MMT addition. The increase in the thermal stability was ascribed to the presence of MMT nanolayers, which acted as barriers to minimize the permeability of volatile degradation products out from the material. Byung-Wan Jo et al reported increase in tensile modulus and glass transition temperature by 37 % by 25 % due to the addition of 5 wt % MMT to unsaturated polyester.
A. Ramkumar et al [16] investigated the fatigue behaviour of MMT/polyamide and reported a lower modulus drop although both the pristine and nanocomposite samples survived for 105 cycles at low applied stress levels. At high stress levels, polyamide-6 samples exhibited a rapid drop in modulus.

Vinylester has the combination of superior mechanical properties of epoxy resin and ease of processing of polyester resin [17-18]. Nanoclay/vinylester has high potential for marine structural applications because of the inherent advantages of both the constituents [19]. Vinylester has superior barrier properties and nanoclay dispersion in vinylester further improves the diffusion properties as well as fire retardation behavior [20].

Review of literature [1-20] indicated that MMT has been explored as nanofiller in many polymeric resins for property improvements. The influence of addition of MMT to vinylester on the mechanical, fire and thermal properties has been scarcely reported. The primary objective of this research was to disperse MMT in vinylester considering 2 to 8 wt % MMT to study the optimal level of MMT addition at which exfoliation of nanoclay in vinylester is obtained.

The exfoliation was examined using XRD and TEM. The effect of MMT addition to vinylester on its glass transition temperature, microhardness and thermal stability using TGA was investigated. The influence of MMT addition to vinylester/glass on its mechanical properties such as tensile, flexural, ILSS, impact and fatigue behavior was examined. The influence on the fire behavior of vinylester/glass was studied based on HBR, VBR and Limiting Oxygen Index (LOI). The research was intended to evaluate MMT as nanofiller for vinylester based composites to study its potential for a variety of applications such as marine, aerospace, automotive and the like.
3.2 Experimental

3.2.1 Materials

The matrix resin used in this study was ECMALON 9911 Bisphenol epoxy based vinylester resin supplied by ECMAS, Hyderabad, India. The curing agents used were cobalt naphthenate, di-Methyl acetamide and methyl ethyl ketone peroxide, Naphtha Resins and Chemicals Pvt, Ltd, Bangalore, India. The nanoclay used was MMT K-10 supplied by M/s Sigma-Aldrich, USA. Glass fibres of 200 gsm, coated with an emulsion based sizing agent, plain-woven fabric type were supplied by VETROTEX, India.

3.2.2 MMT/vinylester/glass Nanocomposites preparation

The nanocomposites were fabricated in two steps: preparation of MMT/vinylester gel coat using ultrasonication and fabrication of gel coat/glass laminates using hand layup technique. MMT in 2 to 8 wt % were dispersed using ultrasonicator for two hours. 2 wt % each of Di-Methyl acetamide as promoter, Cobalt napthalate as accelerator and methyl ethyl ketone peroxide (MEKP) as catalyst were pre-mixed in MMT/vinylester at room temperature to initiate the cross-linking process. MMT/vinylester/glass laminates were fabricated using hand layup technique. The fibre to resin weight ratio was maintained at 65:35 and the specimens were cured at room temperature for 24 hours as per the manufacturer’s recommendations for marine applications.

3.3. Results and Discussion

3.3.1 X-Ray Diffraction Studies

XRD is the most useful method to evaluate the d-spacing between the clay layers, which is used to study the degree of dispersion uniformity of the nanoplatelets in the polymer matrix. The angle and the d-spacing are related through Bragg’s Law shown in equation (3.1).

\[ n\lambda = 2d \sin \theta \]

where, \( n \) is an integer, \( \lambda \) is the wavelength, \( \theta \) is the angle of incidence, and \( d \) is the interplanar spacing of the crystal. XRD patterns of the neat MMT and MMT/vinylester
nanocomposites are shown in Fig. 3.1. Nanocomposites are of two types from the structural standpoint. They are intercalated and exfoliated. In intercalated nanoclay, the polymer molecules are inserted within the silicate layers of the clay forming well-ordered multi layers and in exfoliated nanoclay the silicate layers break into single platelets and orient themselves in a random manner [19]. In order to verify whether the resin molecules entered between the clay layers or not, the diffractograms of the pure MMT was compared with those of the MMT dispersed vinyl ester. MMT showed d-spacing of 13.28 Å at 2θ = 7.2°. The absence of distinct peaks in 2 wt % and 4 wt % MMT/vinyl ester confirmed uniform dispersion of MMT. But, the appearance of distinct peaks in 6 wt % and 8 wt % MMT/vinyl ester indicated non-uniform distribution and possible agglomerations of MMT.

3.3.2 Transmission Electron Microscopy (TEM)

TEM images of 2 to 8 wt % MMT /vinylester are shown in Fig. 3.2 (a-d). Micrographs of 6 and 8 wt % MMT /vinylester specimens show non-uniform distribution of MMT with agglomerations. Exfoliation and uniform distribution of MMT can be clearly observed in the micrographs of 2 and 4 wt % MMT /vinylester. Thus, the TEM micrographs provide evidence to the XRD observations of exfoliated MMT in vinyl ester. Higher loading of MMT increases the viscosity of the polymer leading to the formation of agglomerations. Hence, up to 4 wt % MMT is suitable for polymer nanocomposites.

3.3.3 Differential Scanning Calorimetry

Differential scanning calorimeter was used to determine the glass transition temperature (Tg) of MMT/vinyl ester using heat flow verses change in temperature. Fig.3.3. shows the DSC thermograms of MMT/vinyl ester. The Tg of the nanocomposites increased with increase in MMT loading, which may be due to the presence of clay platelets leading to better MMT dispersion and exfoliation. Also, the interaction of MMT and the vinyl ester network restricted the segmental mobility and thus resulted in higher
Tg [21]. Increase in Tg was around 50 % for 8 wt % MMT dispersed vinylester compared to that of vinylester.

3.3.4 Thermogravimetric Analysis (TGA)

The 2 wt % and 4 wt % MMT/vinylester specimens were subjected to TGA and the weight loss verses temperature is shown in Fig.3.4. The nature of degradation for 2 wt% and 4 wt % MMT/vinylester was similar, but with a significant difference in the residual weight. The residual weight for 2 wt% and 4 wt % MMT/vinylester was observed to be 7.42 % and 9.37 % respectively. This means that addition of MMT resulted in a higher residual weight. The rate of degradation was found to be lower in case of 4 wt % MMT/Vinylester. This indicates that MMT dispersed in vinylester plays an important role in controlling its rate of thermal degradation. The clay platelets present in between the resin molecules offered resistance to their thermal degradation behavior. Hence, the rate of degradation showed a lowering trend with the increase in MMT content [19].

3.4. Mechanical Properties

3.4.1. Microhardness or Vickers hardness test

Hardness of a material is defined as the resistance to deformation, particularly permanent deformation, indentation or scratching. As shown in Fig.3.5, Vickers hardness increased by 12.5, 12.8, 13.4, 14.3 and 14.8 with the addition of MMT in 0, 2, 4, 6 and 8 wt% respectively to vinylester. In order to provide reliable hardness values corresponding to the total hardness of the nanocomposites, the imprints under each load should be larger in size than the dimensions of the dispersed intercalated structures shown in Fig.3.6. Vickers hardness increased by 18.5 % with the addition of 8 wt % MMT to vinylester. This may be because the intercalated/exfoliated MMT platelets formed network like structure with vinylester molecules when effectively restricted the indentation and leading to superior microhardness [21].
3.4.2. Flexural and Tensile behavior of MMT/vinylester/glass

Flexural strength, Flexural Modulus, UTS and Young’s Modulus increased with the addition of up to 4 wt % MMT to vinylester/glass by 47 %, 40 %, 30 % and 24 % respectively and the same decreased for further loading of MMT. Flexural strength Fig.3.7, UTS Fig.3.8, Flexural modulus Fig.3.9, Young’s modulus Fig.3.10, strain to failure in flexural loading Fig.3.11 and strain to failure in UTS Fig.3.12. The strain to failure in both tensile and flexural loading increased with increase in MMT loading up to 4 wt % and decreased for further loading. The increase in mechanical properties along with increase in strain to failure up to 4 wt % MMT loading indicates that the nanocomposite showed good ductility which is encouraging from formability stand point.

The improvements in mechanical properties are attributed to the dispersion of MMT and the interfacial adhesion between vinylester matrix and MMT so that the mobility of chain matrix is restricted under loading [1]. The strong interfacial interaction that exists in the composites may also restrict the mobility of the matrix in the interface between the fiber and the matrix or between MMT and the matrix allowing better stress transfer to the glass fibres inside the composite [22]. Dispersing beyond 4 wt % MMT in vinylester was difficult due to increase in viscosity resulting in the formation of agglomerates, which acted as stress concentration and crack initiation sites. Therefore, mechanical stirring, shear mixing and ultrasonic separation techniques only cannot be effectively used to create good dispersion of MMT when higher levels of loading is to be included in polymers. In general, however, addition of low and medium levels of MMT as reinforcing filler in polymer matrix using these existing methods has produced encouraging results.

MMT particles have the unique ability to improve the Young’s Modulus of the composites [22]. The specific characteristics of nanocomposites such as strength and modulus can only be improved if MMT is well dispersed in the surrounding polymer [24-26]. MMT has a strong tendency to agglomerate, and achieving homogenous dispersion is difficult. This is due to the reason that the free volume which allows MMT to move
around decreases for relatively high MMT content. The higher the volume fraction of MMT, lower is the free volume for each MMT particle to move around in the resin [27].

3.4.3. Interlaminar Shear Strength of MMT/vinylester/glass

The presence of MMT in vinylester resulted in the strong adhesion between MMT and vinylester and thus improved the shear properties of the composites. The decrease in ILSS for more than 4 wt % MMT composites is due to their less uniform dispersion in the polymer. Typically, as a particle-reinforced system becomes more homogeneous, the detrimental effects of the phenomena such as particle clustering are reduced. The decrease in the number of stress concentrators present in the microstructure directly leads to increase in the mechanical strength of the material. Changes in the particle filler content and the dispersion method may cause variations in ILSS. Greater the degree of nanoclay exfoliation, greater is the ILSS. 4 wt % MMT dispersed vinylester/glass showed 72 % increase in ILSS compared to that of vinylester/glass as shown in Fig.3.13. The extent of improvement in ILSS achieved in this research is much superior to that reported by Zhen Zing Kong et al [28]. The optimum level of nanoclay for fabricating the nanocomposites was found to be 4 wt %, as it was difficult to disperse greater than 4 wt % due to increase in viscosity of the nanoclay/vinylester. The same was evidenced by the appearance of agglomeration which are basically areas of high stress intensity which can cause decrease in interlaminar shear strength.

3.4.4 Impact strength of MMT/vinylester/glass

The impact energy of vinylester/glass increased by 38%, 85%, 25% and 10% due to the dispersion of MMT by 2, 4, 6 and 8 wt % respectively as shown in Fig.3.14. The increase in impact energy for 4 wt % MMT dispersion is due to improved interfacial bonding between the fibres and the matrix modified by MMT. The drop in impact energy at 6 wt % and 8 wt % MMT based samples was mostly due to the voids existed inside the nanocomposites. These might have been created while dispersing MMT in the resin with the hardeners. It was because when the MMT loading levels increased, the material itself became too viscous and sluggish. Viscosity of the clay-resin mixture increased with
increase in MMT loading. Once the hardener was added to the premixed MMT/ vinylester, big bubbles were easily created and trapped inside the sluggish mixture, which were permeated to the entire volume increasing the number of voids.

Later on, when it was tested for impact behavior the bubbles inside could not withstand the force and the same might have initiated cracks to propagate throughout the sample. This is why higher levels of loading showed lower levels of improvement in impact energy [26]. The continuous improvement in impact energy of the nanocomposites may be due to their morphology. The MMT/vinylester changed from the phase separated microcomposite morphology to the intercalated morphology and then to the exfoliated morphology. As more and more MMT transformed into exfoliated clay, it formed a network and absorbed the impact energy or prevented the crack propagation.

3.4.5. Morphology Studies using SEM

Tensile fractured surfaces were examined using Scanning Electron Microscopy. Fig.3.15 (a-b) show reasonably good fibre matrix bonding between vinylester and glass. The fractured surfaces show fibre breakage and some amount of fibre pull out. Fig.3.15 (c-d) pertaining to 2 wt % MMT/vinylester/glass show good dispersion of MMT in vinylester without any agglomerates. MMT is found adhered to the fibre and fibre breakage is dominantly observed in the micrographs. Fig.3.15 (e-f) of 4 wt % MMT / vinylester showed good dispersion of MMT in vinylester matrix. MMT is well exfoliated in the matrix as indicated by the absence of agglomerates.

The same is evidenced by the X-Ray diffractograms. Fig.3.15 (g-h) pertaining to 4 wt % MMT / vinylester/glass show good interfacial bonding between MMT and glass as well as MMT/vinylester. These micrographs also evidence fibre breakage and absence of MMT agglomerates. MMT is uniformly distributed and adhered to vinylester and glass. Fig.3.15 (i-j) pertaining to 6 wt % MMT/vinylester/glass show greater amount of agglomerates causing stress concentration sites resulting in drop in mechanical
properties. Clusters of MMT are found everywhere surrounding the fibre and sudden failure of tensile specimens evidenced brittle failure.

3.4.6 Fatigue behaviour of MMT/vinylester/glass

Number of cycles to failure of MMT/vinylester/glass at 60 % and 80 % of flexural peak loads and 6 Hz and 9 Hz frequencies was studied to investigate the influence of MMT on the fatigue behavior of vinylester/glass. Number of load cycles verses number of stress cycles is presented in Fig.3.16 to Fig.3.19. Addition of MMT showed improvement in fatigue life of vinylester/glass. Addition of 4 wt % MMT showed 54.5 % improvement in fatigue life over vinylester/glass at 6 hz and 60 % peak load. At 9 hz frequency 4 wt % MMT/vinylester/glass showed superior fatigue behavior up to 15,000 cycles. Similar results are reported by [16]. For the same applied stress, MMT/vinylester/glass exhibited longer fatigue life than vinylester/glass. MMT addition yielded greater improvement in fatigue life at a low stress or a high cycle regime and is less potent in improving life at high stress levels. At high stress levels the nanoparticles are less resistive in suppressing the rapidly propagating cracks. This is explained on the basis of stress intensities or strain densities [29]. At high stress levels the fatigue crack grow at a rapid rate and at several fronts because of the high stress intensity and high strain density respectively. The nanoparticles become relatively ineffective in slowing down the onset or subsequent growth of damage at high stress intensities [30].

3.4.7. Fatigue damage mechanisms

Fig.3.20 shows SEM micrographs of fatigue fractured specimens of vinylester/glass and 4 t % MMT/vinylester/glass subjected to fatigue at 60% and 80% peak loads. Both these specimens showed fibre breakage on the fracture surface. It is interesting to note that the size of the deformation in general increased in both width and depth with decrease in the stress level during fatigue or alternatively with an increase in fatigue life. The mechanisms behind the formation and growth of deformation occur in two phases. In the first phase, microcracks are formed during the early stage of fatigue
loading at some weak locations where there are high stress concentrations. In the second phase, localized polymer deformation occurs due to strain concentration around these microcracks which in turn promotes the deformation. Lower the applied stress level, the longer this stage lasts. Deformation grows in a stable fashion with increasing number of fatigue cycles before they coalesce into major cracks and finally fails. At high stress levels, they tend to coalesce rapidly, leading to premature fracture without extensive growth of deep and wide dimples. These observations suggest that the elongation or stretching of the localized deformation zones or dimples is highly dependent on the applied stress. Morphology of the nanoclay induced deformation is considerably different from that of vinylester/glass. Vinylester/glass showed wider and shallower deformation than MMT/vinylester/glass. As observed from the micrographs of 14 a) and b), at 60 % load, the size of the fatigue damage in vinylester/glass was greater than that of MMT/vinylester/glass. But, at 80 % load, the there was no much difference in the level of fatigue damage between vinylester/glass and MMT/vinylester/glass as both the specimens showed fibre breakage and delamination of nearly same extent. These observations are in conformance with those of [29].

3.5. Fire Retardation Behavior

3.5.1. Horizontal and Vertical Burning rates

The fire retardation of MMT/vinylester/glass improved monotonically with increase in MMT loading from 2 wt % to 8 wt %. The results of vertical and horizontal burning rates are presented in Table 3.1 and Fig. 3.21. The 8 wt% MMT dispersed samples showed maximum decrease in VBR and HBR of about 27 % and 40 % respectively compared to that of vinylester/glass. The formation of a surface layer during pyrolysis of the nanocomposites was usually considered to be the main reason for improved fire retardancy. This is because this layer acts as a heat barrier which preventing heat from transferring into unpyrolysed material. Also it increases the surface re-radiation heat losses with surface temperature. Adding MMT to vinylester/glass reduces the flammability and hence MMT acts as a good flame retardant [20].
3.5.2. Fire Retardation Behaviour using LOI

Fennimore and Martin developed LOI method [31]. In the present research the values of LOI of nanoclay/vinylester composites were found to be in the range of 20-35. In practice, the material is often called self extinguishing if LOI is greater than 24. Hence, the specimens used in the present research can be classified as fire retardant materials. LOI increased with increase in MMT loading of vinylester and vinylester/glass shown in Table 3.2. The best LOI results obtained for addition of 8 wt % MMT to vinylester and vinylester/glass composites were 18% and 25 % respectively shown in Fig.3.22.

The presence of MMT seemed to increase the stability of the char promoting mechanical cohesion of the crust which reduces the amount of heat transferred to the polymer, limiting the diffusion of oxygen to the area of nanocomposition. This impeded the escape of volatiles demanding more oxygen to be supplied to overcome the barrier coating which finally increased the LOI of the material. The LOI results clearly indicate that the nanocomposites of the present study can be used for fire resistance applications.

3.6 Conclusions

Influence of addition of MMT to vinylester on the mechanical, thermal and fire behaviour of vinylester and vinylester/glass was studied based on dispersion and characterisation experiments. XRD and TEM results showed that exfoliation occurred in 2 wt % and 4 wt % MMT dispersed in vinylester. In 6 and 8 wt % MMT dispersed vinylester, the resin molecules could only penetrate in between the clay platelets causing intercalation, and could not delaminate the platelets. Addition of 2 to 8 wt % MMT to vinylester increased the glass transition temperature and microhardness of vinylester. TGA thermograms showed that addition of 2 and 4 wt % MMT to vinylester resulted in higher residual weight and lower rate of thermal degradations. Mechanical properties such as Flexural strength, UTS, Young’s Modulus, interlaminar shear strength and impact...
strength of MMT/vinylester/glass showed improvements up to 4 wt % MMT addition to vinylester/glass. SEM micrographs evidenced that MMT had a tendency to form agglomerates beyond 4 wt % addition to vinylester/glass.

Addition of 4 Wt % MMT showed 54.5 % increase in fatigue life over vinylester/glass at 6 Hz and 60 % peak load. At 9 Hz frequency 4 wt % MMT/vinylester/glass showed superior fatigue behavior up to 15,000 cycles. Fatigue damage mechanism was studied using SEM, which occurred in two phases. Microcracks formed during the early stage of fatigue loading at some weak locations where there are high stress concentrations. Localized polymer deformation occurred due to strain concentration around the microcracks leading to fatigue failure. Fire retardation was monotonic with increase in MMT up to 8 wt %. Addition of 8 wt % MMT to vinylester/glass decreased VBR and HBR by 27 % and 40 % respectively. The corresponding improvements in LOI were 18 % and 25 % respectively. MMT dispersed Vinylester based nanocomposites, with enhanced properties, can find applications in areas such as marine, automotive, aerospace and the like.
### Table 3.1 Horizontal and Vertical burning rates of MMT/vinylester/glass

<table>
<thead>
<tr>
<th>MMT (wt %)</th>
<th>Burning Rate</th>
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<tr>
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<td>HBR (mm/min)</td>
<td>VBR (mm/min)</td>
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</tr>
<tr>
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</table>

### Table 3.2 Limiting oxygen index percentages

<table>
<thead>
<tr>
<th>MMT Loading (Wt %)</th>
<th>MMT/Vinylester LOI %</th>
<th>MMT/Vinylester/Glass LOI %</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>21</td>
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</tr>
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</tr>
<tr>
<td>5</td>
<td>24.8</td>
<td>31.6</td>
</tr>
</tbody>
</table>
Fig. 3.1 X-ray Diffractograms of MMT/vinylester nanocomposites
Fig. 3.2 TEM of a) 2 wt % MMT/vinylester, b) 4 wt % / vinylester, c) 6 wt % MMT /vinylester and d) 8 wt % MMT/vinylester
Fig. 3.3 Effect of MMT loading on Glass transition temperature of vinylester

- a- VE, 71.31°C
- b- 2wt% MMT/VE, 95.16°C
- c- 4wt% MMT/VE, 111.03°C
- d- 6wt% MMT/VE, 116.63°C
- e- 8wt% MMT/VE, 122.92°C
Fig. 3.4 Effect of MMT loading on thermal degradation of vinylester

Fig. 3.5 Vickers Hardness of MMT/vinylester
Fig. 3.6 Micro hardness indentation of a) Vinylester, b) 2 wt % MMT/vinylester, c) 4 wt % MMT/Vinylester, d) 6 wt % MMT/Vinyleter, e) 8 wt % MMT/Vinylester
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Addition of MMT (Wt%) to Vinylester / Glass

Fig.3.7 Effect of MMT (wt %) addition to Vinylester /glass Composites on Flexural Strength

Addition of MMT (Wt%) to Vinylester / Glass

Fig.3.8 Effect of MMT (wt %) addition to Vinylester /glass Composites on UTS
Addition of MMT (wt%) to vinylester/glass

Fig. 3.9 Effect of MMT (wt %) addition to Vinylester /glass Composites on Flexural Modulus

Addition of MMT (wt%) to vinylester/glass

Fig. 3.10 Effect of MMT (wt %) addition to Vinylester /glass Composites on Young’s Modulus
Fig. 3.11 Effect of MMT (wt %) to Vinylester/glass on strain to Failure in flexural loading

Fig. 3.12 Effect of MMT (wt %) to Vinylester/glass on strain to Failure in tensile loading
Addition of MMT (Wt%) to Vinylester / Glass

Fig. 3.13 Effect of MMT (wt %) addition to Vinylester / glass composites on Inter Laminar Shear Strength

Addition of MMT (Wt%) to Vinylester / Glass

Fig. 3.14 Effect of MMT (wt %) addition to Vinylester / glass Composites on Impact Energy

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Fig.3.15 Scanning Electron Micrographs: a) and b) VE/glass
c) and d) 2wt% MMT/VE/glass, e) and f) 4wt% MMT/VE
g) and h) 4wt% MMT/VE/glass, i) and j) 6wt% MMT/VE/glass
Fig. 3.16 Fatigue life of MMT/Vinylester/glass composites in 6 Hz in continues loading

Fig. 3.17 Fatigue life of MMT/Vinylester/glass composites in 9 Hz in continues loading
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Fig. 3.18 Fatigue life of MMT/Vinylester/glass composites in 6 Hz in continues loading.

Fig. 3.19 Fatigue life of MMT/Vinylester/glass composites in 9 Hz in continues loading.
Fig. 3.20 SEM of Fatigue fractured Specimens at 9Hz
a) VE/glass at 60% loading b) 4 Wt% MMT/VE/glass at 60% loading
c) VE/glass at 80% loading d) 4 Wt% MMT/VE/glass at 80% loading

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Fig. 3.21 Effect of MMT (wt %) addition to Vinylester/glass Composites on Fire retardation

Fig. 3.22 Effect of MMT (wt %) addition to Vinylester/glass composites on Limiting Oxygen Index
3.7 References


